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15 AUGUST 1975

ENGINEERING AND DESIGN

# HYDRAULIC DESIGN OF LOCK CULVERT VALVES

DEPARTMENT OF THE ARMY•CORPS OF ENGINEERS
OFFICE OF THE CHIEF OF ENGINEERS

DEPARTMENT OF THE ARMY
Office of the Chief of Engineers
Washington, D. C. 20314

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Engineer Manual
No. 1110-2-1610

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HYDRAULIC DESIGN OF LOCK CULVERT VALVES

1. Purpose. The purpose of this manual is to present hydraulic design data on control valves for navigation lock filling and emptying systems.

2. Applicability. This manual applies to all field operating agencies concerned with Civil Works design, construction, and operational maintenance.

3. General. This manual is a guide in the design of control valves for navigation lock filling and emptying systems.

FOR THE CHIEF OF ENGINEERS:

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Colonel, Corps of Engineers
Executive

Initial Edition

DEPARTMENT OF THE ARMY EM 1110-2—1610
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Hydraulic Design of Lock Culvert Valves

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# CHAPTER 1. INTRODUCTION

1-1. Purpose. The purpose of this manual is to present data accrued from experience and research that may be useful to Corps of Engineers hydraulic designers concerned with the design of control valves for navigation lock filling and emptying systems. Primarily, the objective is to consider the hydrodynamic forces that enter into the design of valves. However, the interrelationship of structural features, operational procedures, and hydraulic performance will be discussed when pertinent to an understanding of the problems involved. Consideration will be given only to valves used to control flow in relatively long culverts. Valves in tubes with a length less than about 5 diameters, such as might be installed in or around the lock service gates, present a somewhat different type of design problem than those installed in longer culverts;, and since they are rarely used in any but very low-lift modern locks, they will be omitted from the discussion. Service gates which in themselves either constitute the primary filling system or are used as auxiliary devices, such as vertical-lift gates, tainter gates, sector gates, bascule gates, etc., also will not be treated in this manual.

1-2. Applicability. The provisions of this manual are applicable to Corps of Engineers Divisions and Districts concerned with civil works design, construction, and operational maintenance.

1-3. References.

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m. American Society of Civil Engineers, "Manual on Lock Valves," Manuals of Engineering Practice No. 3,1930, Committee on Lock Valves, Waterways Division, New York, N. Y.

n. Murphy, T. E., "Hydraulic Model Investigation of Lock Culvert Valves," Jan 1942, Special Engineering Division, Panama Canal Zone, Diablo Heights, Canal Zone.

1-4. Typical Filling and Emptying System. The most common type of filling and emptying system used in modern locks has a longitudinal culvert in each lock wall extending from the upper pool to the lower pool, with a streamlined intake at the upstream end and a diffusion device at the downstream end. Flow is distributed from the longitudinal culverts in and out of the lock chamber by short ports or secondary culverts in the floor of the lock chamber. Two valves are required in each longitudinal culvert, one between the intake and the lock chamber manifold to release flow in the filling operation, and the other between the chamber manifold and the discharge diffuser to empty the lock chamber.

1-5. Types of Lock Valves.

a. In 1930 the America; Society of Civil Engineers published a manual on lock culvert valves which described valves at 12 projects, "all of reasonably recent construction." At these 12 projects, seven types of valves were used, namely stoney gate, cylindrical, wagon body, butterfly, spool, slide gate, and tainter. However, since about 1930, tainter valves (an adaptation of the tainter gate developed by Jeremiah B. Tainter and patented by him in 1885 for control of flows over spillway crests) have been used almost exclusively in hydraulic systems of major locks in North America. Among the first locks in which tainter valves were used are Lock No. 2 on the Mississippi River, completed in 1930, and the Welland Ship Canal Locks in Canada, completed in 1933. The valves in these and several other installations were oriented in the manner of the conventional tainter gate, that is, with the trunnions downstream of the skin plate causing the convex surface of the skin plate to face the flow and seal along the upstream end of the valve well. When the Pickwick Lock on the Tennessee River was being designed for a lift of 65 ft, model tests showed that during the opening period the pressure gradient immediately downstream of the valve skin plate dropped below the top of the culvert; this caused large volumes of air to be drawn down the valve well and into the culvert. The air formed large pockets in the model culvert which restricted the flow until sufficient pressure was developed to expel the air through the ports or into the downstream bulkhead recess. Air expelled through the ports erupted at the water surface in the lock chamber with considerable violence, causing disturbances that would be hazardous to small craft.

b. By reversing the tainter valves, that is, placing the trunnions upstream of the skin plate with the convex surface of the skin plate facing downstream and sealing against the downstream end of the valve well, air was prevented from entering the culvert at the valve recess. A typical reverse tainter valve installation is shown in figure l-l. Valves of this general type have been used on all major locks constructed by the Corps of Engineers in recent years.

c. Since data collected in the past 40 years have been concerned with reverse tainter valves, this type of valve will be used in examples in this manual. The reverse tainter valve certainly has proved very satisfactory, it probably will be desirable at most new projects, and its continued use is advocated. However, the designer should consider other types of valves. For instance, if submergence is such that air definitely will not be drawn down the valve well and into the culvert, the use of a tainter valve in the normal position may prove desirable. With the valve in the normal position, loads and load variations on the valve hoist caused by flowing water will be negligible.[n] Structural-design of the trunnion anchorages probably would be simplified. Further, depending upon whether the position of the valve in the lock wall is upstream or downstream from the lock gate, use of the normal position for the tainter valve may prevent large differentials between the water in the valve well and the lock chamber or lower pool. Also, vertical-lift gates which are used extensively in outlet conduits should be suitable as lock culvert valves. The vertical-lift valve would not require the large recess that is necessary with a tainter valve. With one spare gate at an installation, maintenance could be performed without taking the culvert out of service as is necessary with the tainter valve. However, the vertical-lift valve's rollers, wheels, or sliding surfaces might require considerably more servicing than do the elements of the tainter valve. If a vertical-lift valve is considered, certain of the procedures given in this manual could be used in design; but it is suggested that model tests be conducted to develop an optimum bottom shape for the gate and to determine valve hoist loads.

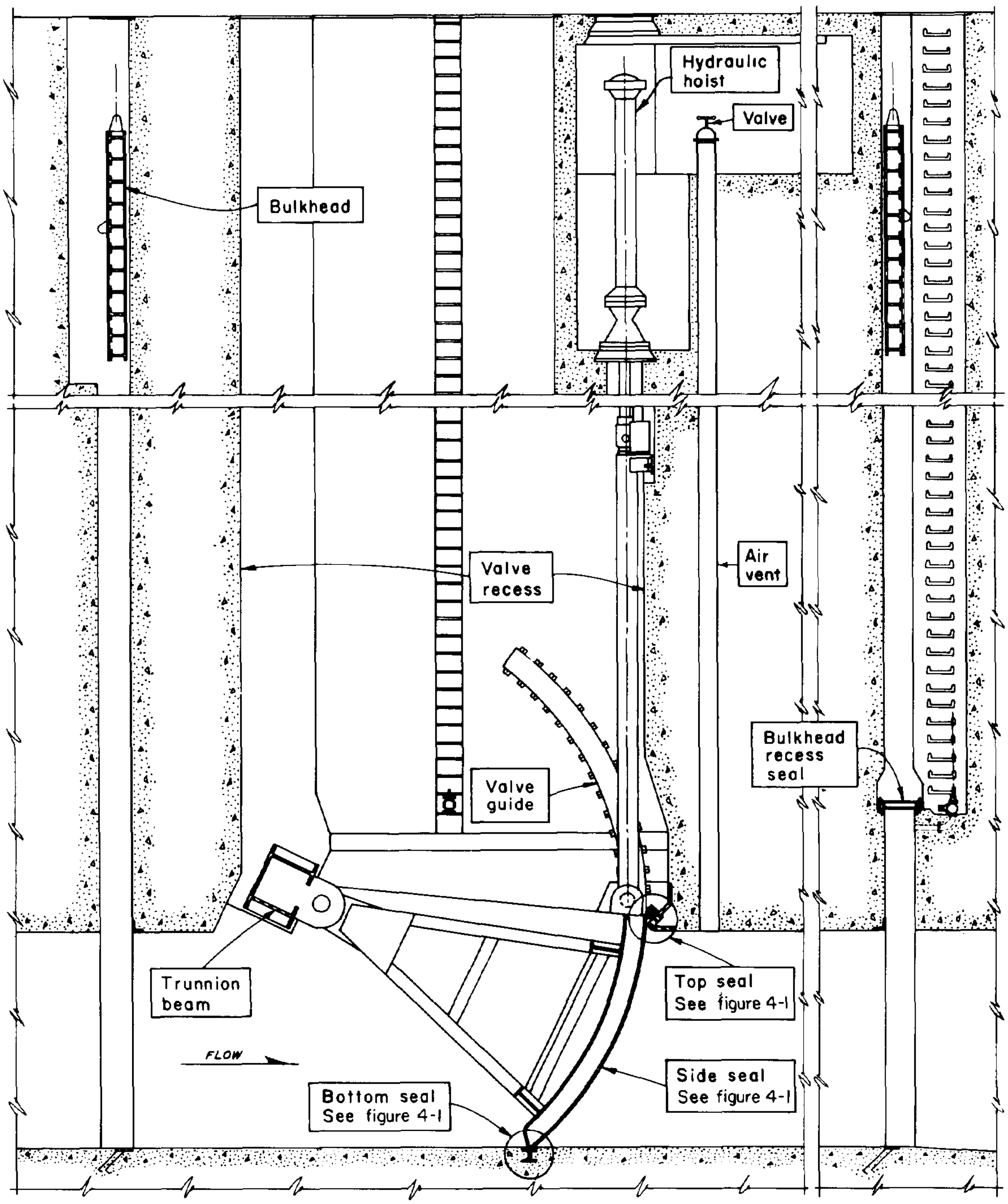



Figure 1-1. Typical reverse tainter valve installation

# CHAPTER 2. AIR IN CULVERT SYSTEMS

## 2-1. Experience with Air in Culvert System.

a. At several old locks (notably Ohio River Lock No. 41, old Wilson Locks on the Tennessee River, and Mississippi River Lock No. 1) portions of the roofs of the culverts between the filling and emptying valves were at elevations higher than the lower pool. This resulted in air seeping into the culvert system and forming pockets along the roof when the chamber water surface was at lower pool level. In the filling operation, the air pockets were compressed and forced along the culvert until expelled through an available exit (valve well, bulkhead recess, or ports into the lock chamber). The air emerged with such explosive force that it endangered personnel on the lock walls, created disturbances in the chamber which were hazardous to small craft, and increased hawser forces on moored tows. Conditions at these locks were mitigated somewhat by installation of blowoff vents, but it was concluded that all air should be sealed from the filling system.

b. When the 92-ft-lift McNary Lock[a] was constructed on the Columbia River six 12-in.-diam air vents, two in the culvert roof and two in the upper portion of each sidewall, were installed immediately downsteam of each valve. During initial operation of the lock, the air vents at the filling valves were capped. Pounding noises, resembling thunder or cannon shots, seemed to come from the bulkhead slots on the downstream sides of the filling valves when the valves were partially open. It was found that opening one of the 12-in.-diam air vents in the roof of the culvert at each valve virtually eliminated these noises. Consequently, the lock has been operated with one air vent open at each valve. Air is drawn through the vent into the culvert system during the valve opening period, is entrained as small bubbles in the highly turbulent flow, and emerges in the lock chamber so entrained that it merely causes the water to look milky. When the valve reaches the full open position, air ceases to be drawn through the vent and all air is rapidly purged from the culvert system still entrained in the flow as small bubbles. No operation difficulties or hazardous conditions have resulted from admitting this controlled amount of air to the culvert system during the valve opening period. Other locks, notably the 63.6-ft-lift Holt Lock on the Warrior River and the 48-ft-lift Millers Ferry Lock on the Alabama River, operate satisfactorily with a controlled amount of air admitted to the culvert system during the valve opening period. In fact, model tests on Holt Lock indicated that a controlled amount of air would reduce hawser forces on moored tows. This seems reasonable since bubble screens are used to dissipate waves and surges in harbors.

c. Thus, while pockets of air in the culvert system are very undesirable, admission of a controlled amount of air during the valve opening period has proved beneficial at high-lift locks.

## 2-2. Recent Field Tests of Cavitation Conditions.

a. Tests were made at three locks--Holt on the Warrior River in Alabama, John Day on the Columbia River in Washington-Oregon, and Millers Ferry on the Alabama River in Alabama--to determine conditions under which a controlled amount of air is needed to quiet the pounding noises such as those heard during initial operation of McNary Lock. A summary of certain of the results of these tests is given in Appendix A.

b. In order to evaluate cavitation potential at various projects, a cavitation parameter, K, is used. The form of this parameter used for lock culvert valves is:

$$K = \frac{P+(P_a - P_v)}{V^2/2g}$$

where

P = gage pressure at the top of the vena contracta of the jet emerging from the partially open valve, ft

$P_a$ = atmospheric pressure, ft

$P_v$ = vapor pressure of water, ft

V = velocity in vena contracta of the jet emerging from the partially open valve, fps

g = acceleration due to gravity, ft/sec$^2$

A value of 33.0 ft has been used for the term $P_a$ - $P_v$ in all cases. This probably is correct within 0.5 ft for conditions at existing locks, and available data do not warrant a more refined value. P and V are computed by a program developed at the U. S. Army Engineer Waterways Experiment Station (WES program, Appendix B) and are independent of local pressures on the roof of the culvert, which are influenced by changes in culvert geometry. The value of this parameter at which cavitation is incipient is termed the cavitation index, $K_i$. Under this procedure, the value of $K_i$ varies with changes in the culvert geometry.

c. Values of the cavitation parameter, K , for the tests described in table A-2 are plotted against percent expansion of the culvert roof in figure 2-1. Also, a line defining $K_i$ recommended for design purposes is shown in this figure. Since Holt test 2 (only one boom) obviously was near conditions for incipient cavitation while John Day test 3B (several booms) was well within cavitation conditions, there is logic in the manner in which the $K_i$ line is drawn. At Holt and John Day Locks where the culvert roofs slope up downstream from the filling valves there is additional backflow of water into the low pressure zone downstream from the valve. This additional circulation, or water venting as it is sometimes called, results in an increase in pressure on the culvert roof. Measured pressure increases have been plotted as pressure drop (initial lock water surface to minimum gradient) reductions in figure 2-2. If this pressure increase was the only quantity changed then computations with measured pressures should allow establishment of a single $K_i$ value for all roof geometries. This is not supported by available data. It is considered probable that both the velocity and depth at the vena contracta also are modified, but accurate measurements to establish the degree of modification would be difficult.

2-3. Selection of Elevation for Culvert Valves.

a. In design, the lock valves must be placed either at an elevation that will result in the minimum value of K being not less than $K_i$ or at an elevation that will result in negative pressures on the culvert roof and vents must be provided in the negative pressure zone. If an elevation for the culvert is determined such that the minimum value of K equals $K_i$, then the culvert should be lowered an additional distance equal to one-tenth of the lift as a safety factor. If vents are to be provided, the culvert should be placed at an elevation that will result in about 10 ft of negative pressure on the culvert roof during normal operation. In locks with lifts up to 100 ft, this will result in the pressure gradient dropping below the culvert roof when or before the valve is about 35% open and thus will provide aeration throughout the critical period of the operation cycle. WES program, Appendix B, computes an elevation for the pressure gradient and this gradient elevation can be used directly to determine the pressure on a level roof but must be modified for upsloping roofs as indicated in figure 2-2.

b. A third alternative to the two procedures suggested in the preceding paragraph is to ignore cavitation potential in siting the valves and to use a slow or delayed valve opening schedule such as is recommended for John Day Lock, see paragraph A-11. In an existing lock this may be necessary but it imposes an undue limitation on a new design. A fourth method that has been proposed but is questionable

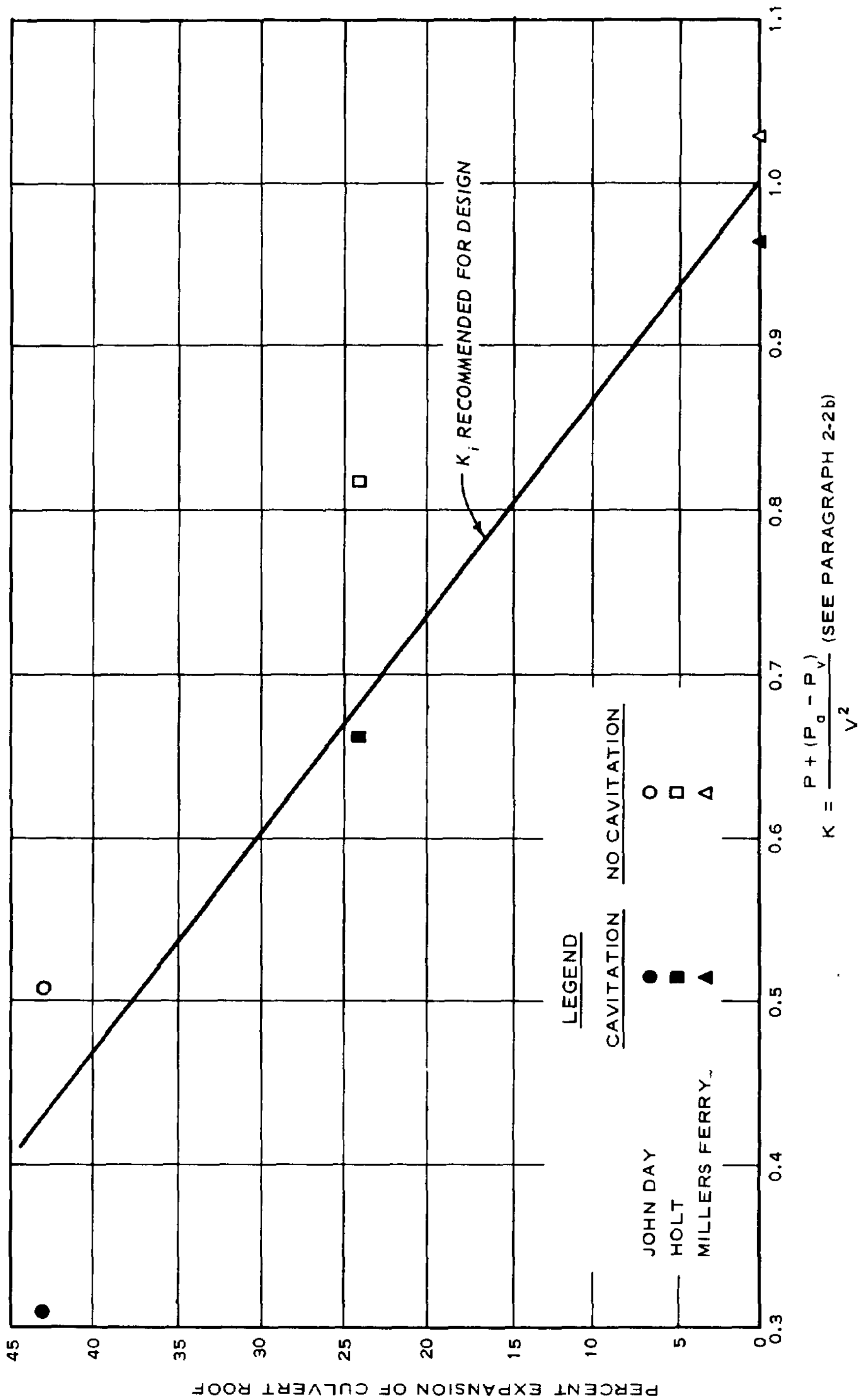



Figure 2-1. Cavitation index

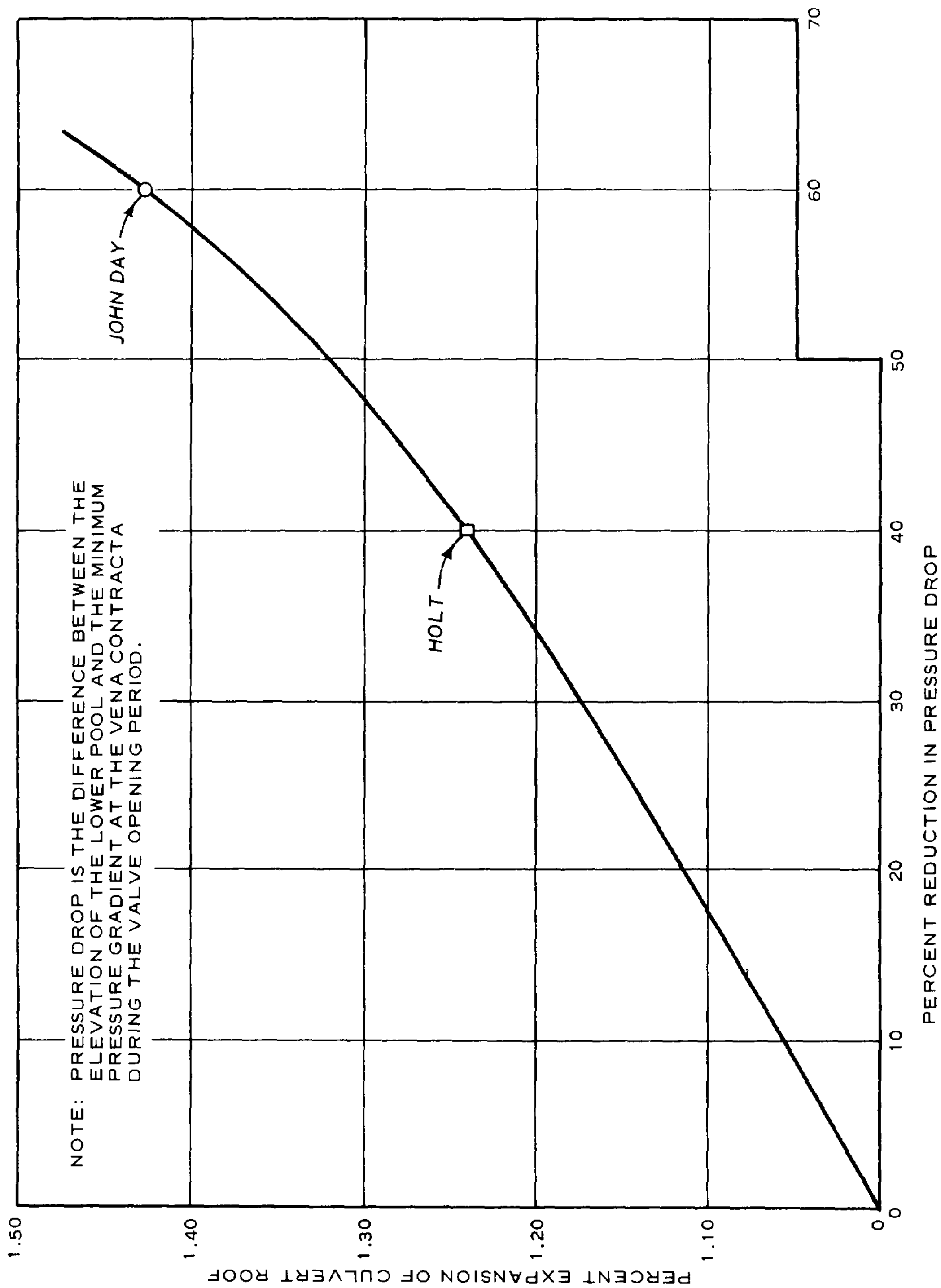



Figure 2-2. Effect of roof expansion on pressure gradient

and not recommended is water-venting by lateral inflow from the lock chamber into the low pressure zone.[d,e] Such water vents will raise the pressure in the critical zone, an asset; but also the lateral inflow will increase turbulence in this zone, a liability. Systematic field tests would be required to determine whether lateral water vents actually are beneficial or detrimental and to establish design rules for their use.

c. In addition to the requirements listed in paragraph 2-3a, in all cases, the highest point in the culvert system between the filling and emptying valves should be at least 5 ft below the lower pool to assure that air will not seep into the culverts when the lock chamber water surface is at the level of the lower pool.

d. Design examples are given in Appendix C.

2-4. Conclusions and Recommendations Regarding Admission of Air into Culvert System. It is concluded that air pockets in the culvert filling system are hazardous but that air bubbles well entrained in the flow can be beneficial. Thus it is proposed that:

a. All elements of the culvert system between the filling and emptying valves should be at least 5 ft below minimum lower pool.

b. In locks with lifts of 40 ft and less, air should be sealed from the culvert system during filling operations. In low-lift locks, where turbulence levels are low, even small amounts of air admitted during filling could collect in pockets and become dangerous. The lock valves should be placed at an elevation that will result in the minimum value of K being greater than $K_i$ and as a safety factor, the valves should be at an elevation equal to at least one-tenth of the lift less than the elevation required for minimum K to equal $K_i$. It is indicated in Example 1, Appendix C, that this will not require excessive submergence of the culverts and therefore, in most cases, should not prove costly.

c. In locks with lifts of 60 ft and greater, the valves should be placed at an elevation that will result in about 10 ft of negative pressure on the culvert roof during filling and air vents should be provided in the low pressure zone. An exception could be made in the very unlikely case that foundation conditions are such that it is economically desirable to place the valves very deep with respect to lower pool. Consideration of Example 2, Appendix C, provides insight into the submergence that would be necessary to prevent cavitation.

d. In locks with lifts of 40 to 60 ft, decision as to whether cavitation will be prevented by submergence or admission of air should be based on economic considerations for the particular project.

2-5. Design of Air Vents.

a. All filling-valve air vents should be provided with means for controlling the amount of air entering the culvert system. Bulkhead slots, valve wells, or other such openings into the culvert should never be allowed to double as air vents for the filling valves.

b. Air vents for emptying valves should be controlled, the same as for filling valves, if flow is discharged into the lower approach to the lock. However, if flow is discharged outside of the lock approach, excessive air is not likely to be harmful and bulkhead slots can be used to double as air vents.

c. A satisfactory vent system for a valve would consist of two independent 12-in.-diam pipes entering flush with the culvert roof between the quarter and third points across the culvert. A vent slot extending across the roof of the culvert as provided in flood control conduits is not required. The vents should enter the culvert roof within the low pressure zone which extends from the valve to the vena contracta of the jet passing under the valve. Location of the vena contracta varies with culvert height and valve opening but vents have performed satisfactorily when placed no more than a distance of one-half of the valve height downstream from the valve well. The vent pipes should be brought through an accessible location, such as the platform that supports the valve operating machinery, and then to openings on the outside face of the lock wall at an elevation above the maximum pool at which the lock will be operated. Openings on the top or inside face of the lock wall are nuisances to personnel on the wall or in the lock chamber. A valve should be inserted in each vent at the accessible location. At the time the lock is put in operation, hydraulic design personnel should assist in determining vent valve settings that will preclude cavitation without an excessive amount of air and thus added turbulence in the lock chamber or lower approach. This should not be difficult as past experience has shown that satisfactory performance can be obtained within a range of settings. The vent valves should be locked in the desired position to prevent accidental changing of the setting.

# CHAPTER 3. HOIST LOADS

## 3-1. Hoist Loads due to Flowing Water.

a. Tainter Valves. Three structurally different types of reverse tainter valves (horizontally framed, double skin plate, and vertically framed) have been used in recent designs of lock filling and emptying systems. The horizontally framed valve is desirable structurally but the double skin plate and vertically framed valves are less susceptible to critical hydraulic loads and load variations during the opening cycle.

b. Interpretation of Data. Hoist loads presented herein are the summation of forces on the valve members due to flowing water considered as a single force acting radially at the valve skin plate. Downpull loads act to rotate the valve to the closed position and uplift loads act to rotate the valve to the open position. Basic data were obtained with the valve at fixed positions and under steady-flow conditions. For each valve position, hoist-load data were obtained for a range of velocities under the valve (inflow or outflow divided by total valve opening). For the plots herein, figures 3-3 to 3-6, the velocity under the valve at each valve position was computed (see Appendix B) for different lifts in a specific lock. Table 3-1 gives the relation of velocity under the valve to lift used in plotting the data in figures 3-3 to 3-6.

Table 3-1. Velocity Under Valve, fps

| Valve Open Percent | Lift, ft 20 | 40 | 60 | 100 |
|---|---|---|---|---|
| 0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 10 | 28.5 | 41.0 | 50.0 | 65.0 |
| 20 | 27.5 | 39.0 | 49.0 | 63.5 |
| 30 | 26.0 | 37.0 | 45.5 | 59.5 |
| 40 | 26.0 | 37.5 | 46.5 | 60.5 |
| 50 | 26.5 | 39.0 | 48.5 | 64.0 |
| 60 | 27.0 | 40.5 | 50.0 | 66.5 |
| 70 | 27.5 | 40.5 | 50.5 | 67.0 |
| 80 | 26.5 | 39.5 | 49.0 | 65.0 |
| 90 | 25.0 | 37.0 | 46.5 | 61.0 |
| 100 | 23.0 | 34.5 | 43.0 | 57.0 |

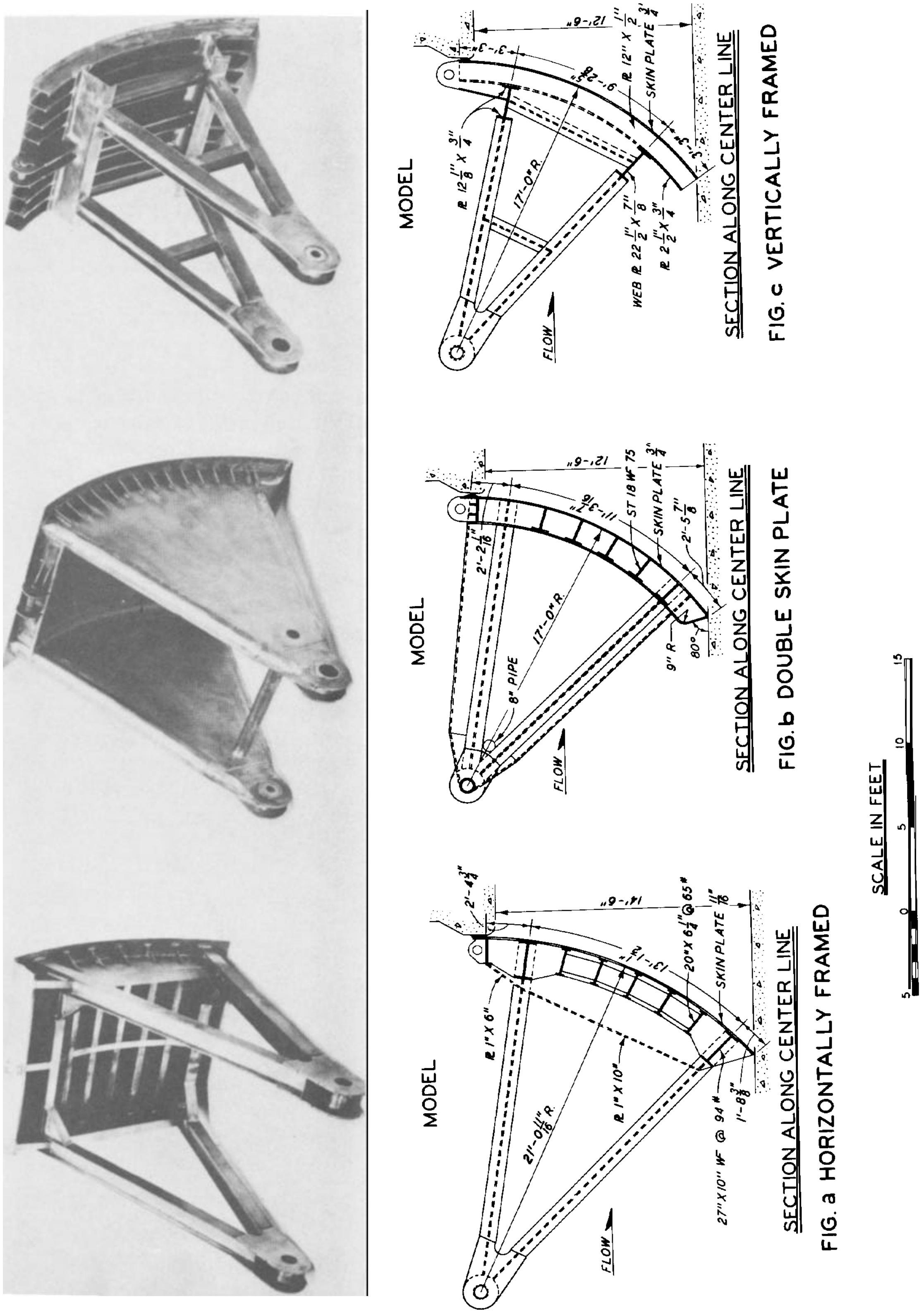



Figure 3-1 tainter type valves

c. Horizontally Framed Valve.

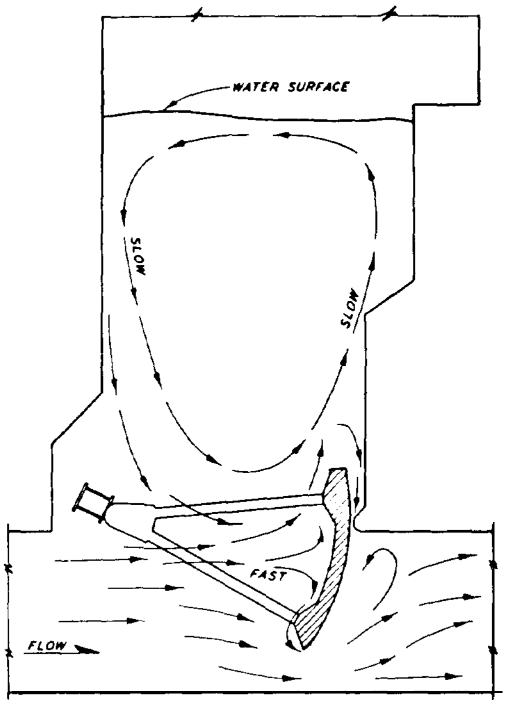
(1) As the name implies, the skin plate is attached directly to a series of horizontal beams and the loads are transmitted to the trunnion arms through vertical frames or girders near the sides of the valve (see fig. 3-1a).

(2) Horizontally framed valves were used almost exclusively in earlier low-lift locks and no inadequacies were indicated until locks in the medium- and high-lift category were required. Serious operational problems with the horizontally framed valve resulting from forces due to flowing water first were encountered in New Lock No. 19, Mississippi River.[f]

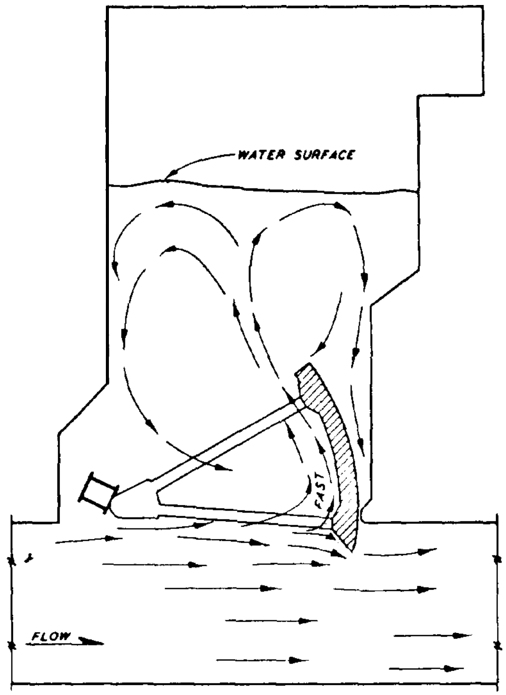
(3) During trial operations at New Lock No. 19 it was found that when a valve was at greater than two-thirds angular opening, flowing water caused pulsating loads which were transmitted through the strut and strut arm, resulting in reversal of load on the operating machinery and a consequent severe clattering in the gear train. The pulsations appeared to increase in magnitude with increased valve opening. The resultant loading conditions were of such severity that remedial action was necessary prior to normal operation of the project.

(4) At New Lock No. 19, the lift is 38.2 ft and flow through the culverts is regulated by 14.5- by 14.5-ft reverse tainter valves. The valves are actuated by electric motors through strut-connected mechanical gear systems. Each valve weighs 28,350 lb, with the strut and strut arm adding weights of 3,500 and 3,100 lb, respectively. With a valve submerged in still water, the load on the hoist varied during an opening cycle from about 21 kips (1.45 kips per foot of valve width) near the closed position to about 31 kips (2.14 kips per foot of valve width) near the open position.

(5) Model tests revealed that under normal operating conditions flowing water caused an average load on the hoist in a downpull direction from a gate opening of 0 to about 75% and in an uplift direction from 75 to 100%. Flow approaching the partially open valve divided at the upstream face of the valve with part of the flow going under the valve and part into circulation in the valve well. When this division was above the lower girder, downpull forces prevailed and below the lower girder, uplift forces occurred. Flow patterns in the valve well during downpull and uplift conditions are shown in figure 3-2. Also, it was revealed that random variations in hoist load increased as the valve opening increased. With the valve near the open position, loads



CONDITION AT WHICH DOWNPULL OBTAINS



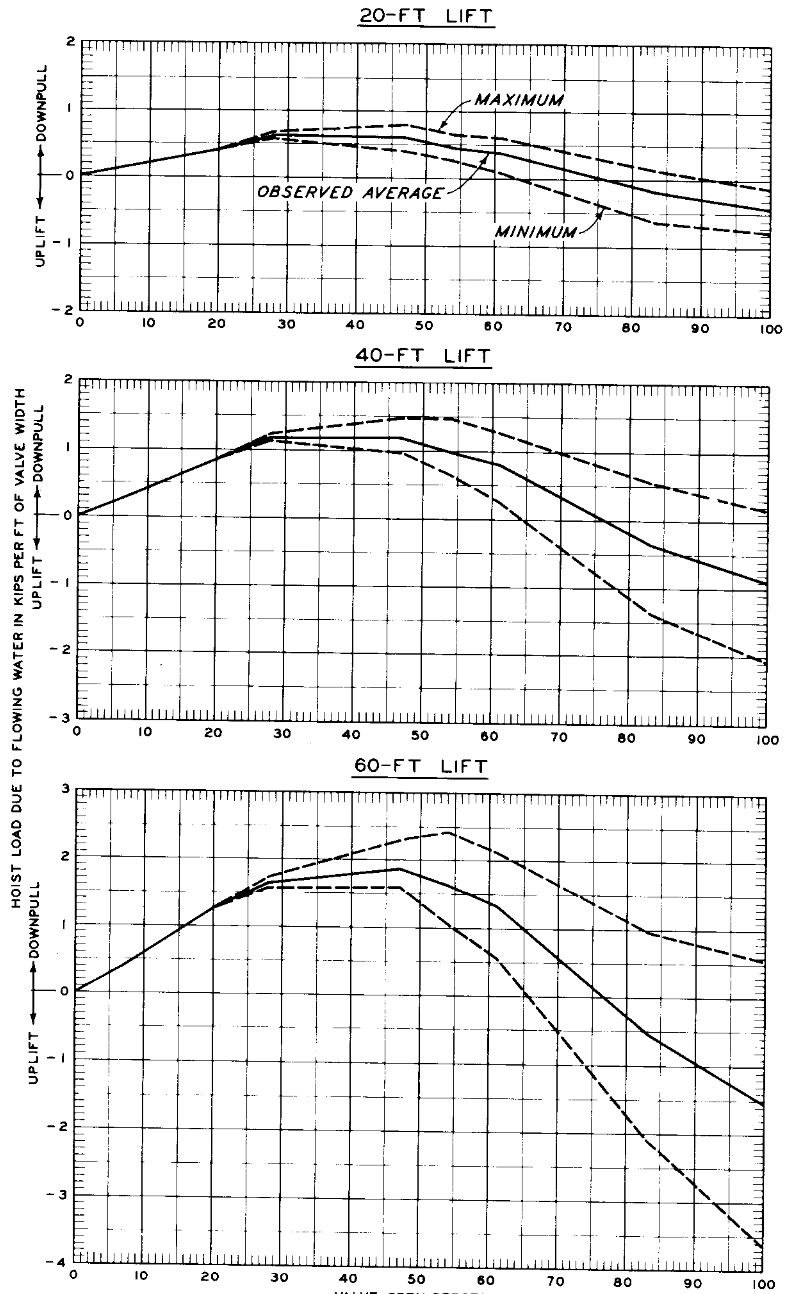
CONDITION AT WHICH UPLIFT OBTAINS

Figure 3-2. Currents in valve recess

on the hoist due to flowing water varied from 12 kips (0.83 kips per foot of valve width) downpull to 48 kips (3.31 kips per foot of valve width) uplift. Thus, with the submerged valve exerting a downpull load of only 31 kips on the valve hoist, it is obvious why severe clattering resulted in the gear train.

(6) Hoist loads due to flowing water obtained in a 1:12-scale model of the valve shown in figure 3-1a at lifts of 20, 40, and 60 ft are plotted in figure 3-3. For planning purposes, these data are considered generally applicable and the prediction of total loads for similar valves based on the width of the valve is justified by the fact that tests have revealed that modifications to valve members above the lower girder have a very small effect on hoist loads. Thus, the height of the valve has a negligible effect on hoist loads except as it modifies the velocity of approach and this is accounted for by plotting valve opening as a percentage of total opening rather than as a specific dimension.

(7) Modifications to the lower girder and the portion of the valve below the girder can have a material effect on valve loads.[f,g] For




(SEE PARAGRAPH 3-1b)

Figure 3-3. Hoist loads, horizontally framed valve instance, installation of a cover plate from the valve lip to the flange of the lower girder resulted in a 30% increase in peak downpull but a 35% decrease in both peak uplift and load variation.

d. Double Skin-Plate Valve.

(1) With the objective of presenting a smooth upstream surface to flow, instead of the projecting edges of the horizontal beams, the transverse beams are covered with a smooth, curved skin plate which results in a streamlining effect (see fig. 3-lb). The inside plate adds rigidity to the leaf and can be utilized in the stress analysis. It is customary to use welded construction, making the tank watertight. Thus, the valve can be operated with the tank filled with air, provided the valve has sufficient weight to counteract its buoyancy as well as the dynamic hydraulic uplift forces. In most instances, however, greater stability is needed and the tank is filled with water and a rust-inhibiting fluid.

(2) General design values of hoist loads due to flowing water obtained in a 1:15-scale model of the valve shown in figure 3-lb at lifts of 20, 40, 60, and 100 ft are plotted in figure 3-4. Results of other tests on valves of this type are given in references a, d, i, j, and k.

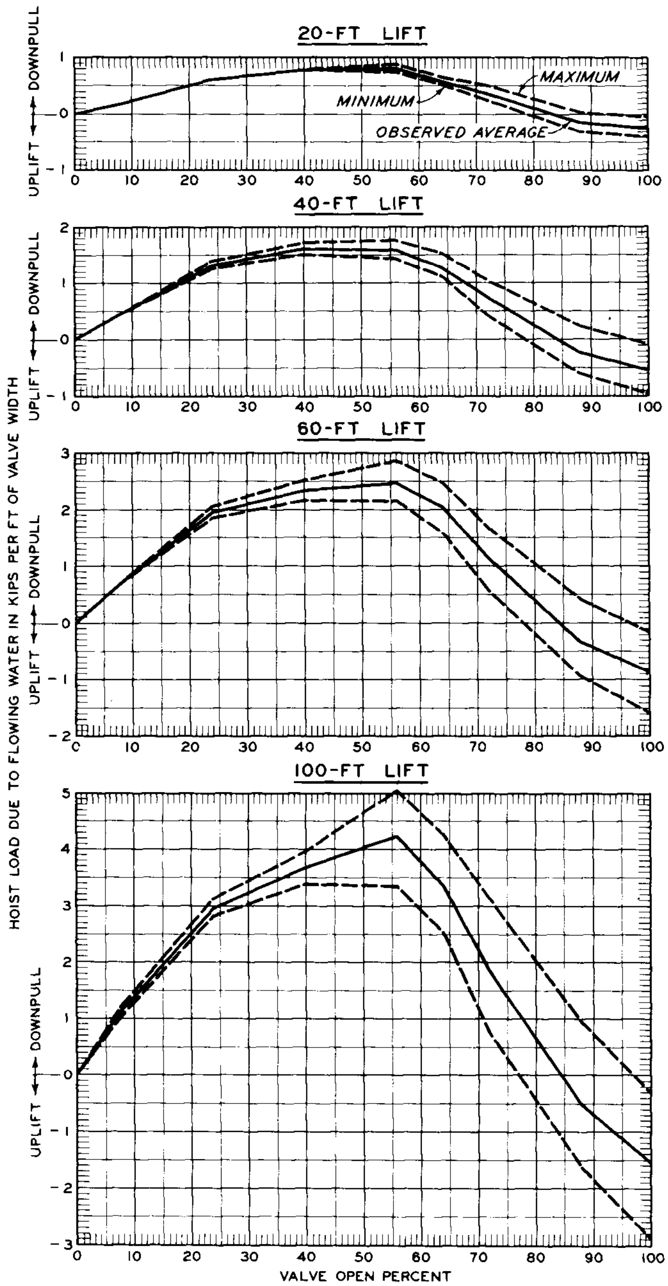
e. Vertically Framed Valve.

(1) In valves of this type the skin plate is attached to a series of curved T-beam ribs along parallel vertical planes (see fig. 3-1c). The water loads are transmitted to the trunnion arms through horizontal girders welded to the outer flanges of the ribs. Thus, open spaces where water can circulate freely are provided between the ribs, and between the skin plate and the horizontal girders.

(2) General design values of hoist loads due to flowing water obtained in a 1:15-scale model of the valve shown in figure 3-1c at lifts of 20, 40, 60, and 100 ft are plotted in figure 3-5. The flanges on the T-beam ribs that transmit loads from the skin plate to the horizontal girders must be narrow. Flanges 2.5 in. wide were suitable in the example valve, but flanges 12 in. wide inhibited the desired circulation and were very detrimental to loading characteristics. Results of an additional test on a valve of this type are given in reference g.

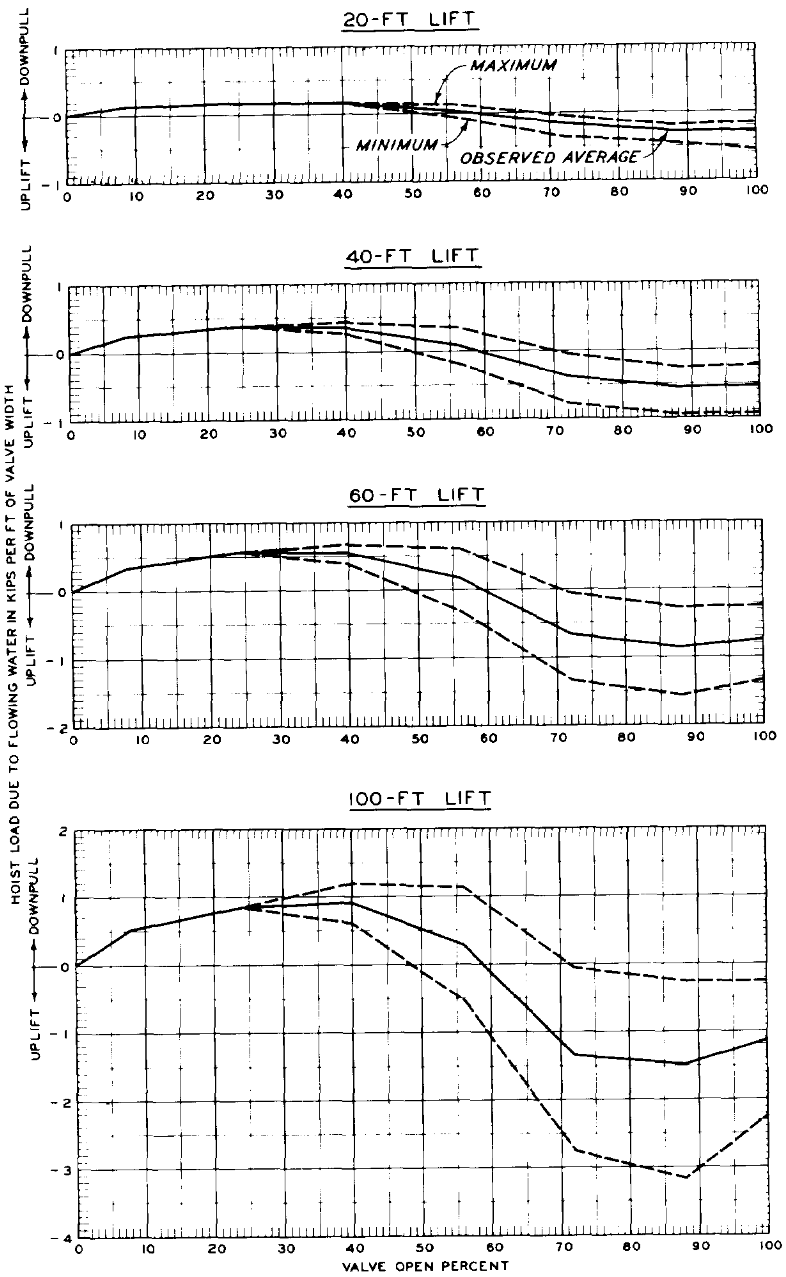
f. General Comments.

(1) Average loads and maximum load variations for the three valves shown in figure 3-1 at a 6O-ft lift are plotted in figure 3-6 to show the relative load characteristics of each valve.



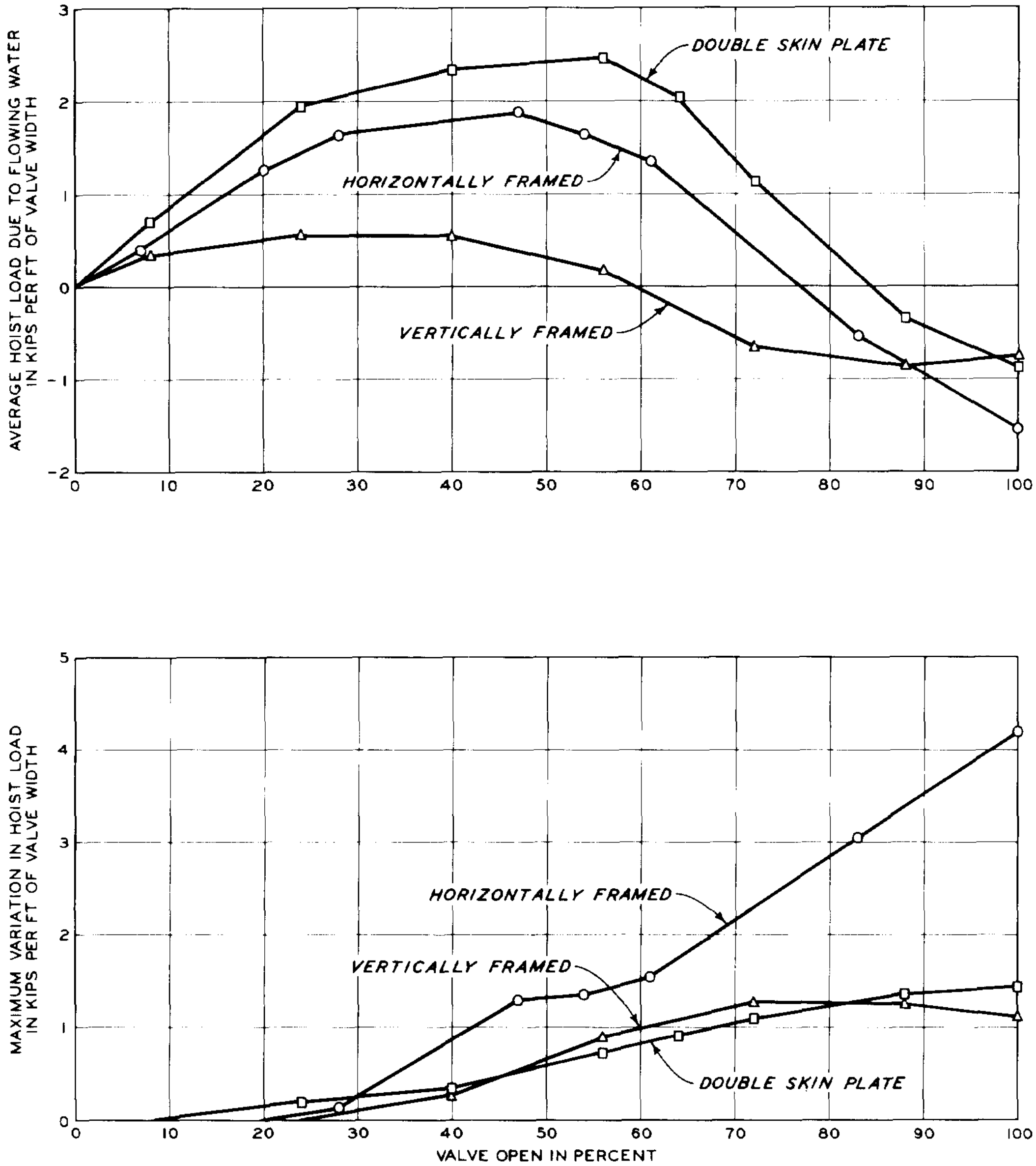

(SEE PARAGRAPH 3-1b)

Figure 3-4. Foist loads, double skin-plate valve




(SEE PARAGRAPH 3-1b)

Figure 3-5. Hoist loads, vertically framed valve




(SEE PARAGRAPH 3-1b)

Figure 3-6. Hoist loads, 60-ft lift

(2) For all three types of valves the two features that most affect loads on the valve hoist due to flowing water are the depth of the lower girder and the extension of the lower lip of the skin plate below the lower girder. A decrease in the depth of the lower girder results in a decrease in peak downpull and load variations and, also, a decrease in the range of valve positions at which downpull occurs and an increase in the range of positions at which uplift occurs. Data are not conclusive as to whether peak uplift is decreased. An increase in the extension of the lower lip of the valve below the lower girder decreases peak downpull and the range of valve positions at which downpull occurs but increases peak uplift and the range of valve positions at which uplift occurs. Load variations remain essentially unchanged.

(3) The effect of load reversals on the valve hoist was demonstrated dramatically at New Lock No. 19 by the severe clattering in the mechanical gear system. When operation is directly from a hydraulic piston, load reversals are not readily noticeable. However, these load reversals still are very undesirable as they are likely to result in excessive wear in the strut connections and could cause other structural damage.

(4) It should be apparent to the designer that consideration of a horizontally framed valve should be limited to locks with lifts of no more than about 30 ft. When designed for equal lifts, the double skin-plate valve usually will be heavier and, particularly if the tank is filled with a rust inhibitor, will require greater hoist capacity than will the vertically framed valve. However, some designers consider a heavy valve to be more stable and thus worth the cost of the additional hoist capacity. Certainly the double skin-plate valve can be used successfully at all lifts. The vertically framed valve probably has economic advantages over the double skin-plate valve and is being used with no problems at the 63.6-ft lift Holt Lock. If this valve is considered for a lock with a very high lift, excess weight may be required to prevent load reversals on the valve hoist.

3-2. Total Hoist Loads. In determination of total hoist loads, the designer must combine the loads due to flowing water (discussed in paragraph 3-1) with loads resulting from: (a) weight of the submerged valve, (b) weight of the operating stem, (c) friction at the side seals and in the trunnion, and (d) head differentials across the top seal (paragraphs 4-4 and 4-4a).

3-3. Peak Head Across Valve.

a. Near the beginning of a filling or emptying operation if a failure of the hoisting mechanism should allow a valve to slam shut, a head across the valve considerably larger than the difference between upper and lower pool would result. Time-history of pressures on each side of the valve can be developed from available formulas concerned with surges and water hammer. Pressure oscillations on each side of the valve will occur with decreasing amplitudes through several cycles. However, the periods of these oscillations are likely to be different on the two sides of the valve; and although individual peaks (positive and negative) on each side of the valve probably will occur during the first cycle, it is possible that the maximum head across the valve will occur later and be less than the difference between the first cycle peaks. Also, there are likely to be reversals in the head across the valve.

b. In a reverse tainter valve installation, the valve well would serve as a surge chamber and thereby delay and reduce the buildup of pressure on the high-head side of the valve. Although the surge in the valve well would spill out at the top of the lock wall the pressure on the valve would result from forces causing flow up the well and could be considerably greater than the difference between the top of the wall and the valve. If the valve is not vented, the pressure on the low-head side of the valve could drop quite rapidly to about -33 ft (one atmosphere negative); with a vented valve, the pressure would drop to essentially atmospheric.

c. Sudden closure of a valve due to breakage of the hoisting mechanism is very unlikely to occur and usually is not considered a design condition. On the other hand, operation that would produce surges is most probable. For many reasons the operator may reverse the valves during or immediately after the opening cycle. A series of tests was conducted in the Cannelton Lock model[1] during which the 18-ft-high by 16-ft-wide filling valves were opened at a rate to reach fully open in 2 min. Immediately upon reaching l/2, 3/4, and then fully open, the valves were reversed and closed at the same rate. The surges generated produced a peak head differential across the valve of about 1.5 times the initial lift.

d. The conditions of peak head across the valve to be used in the structural design should depend on the local situation and judgment on the part of the designers. Certainly all designs must provide for the head created by the abnormal operation described in paragraph 3-3c. The hydraulic designer should describe the possible loadings that could result from operational and accidental closure of the valves during a filling or emptying operation.

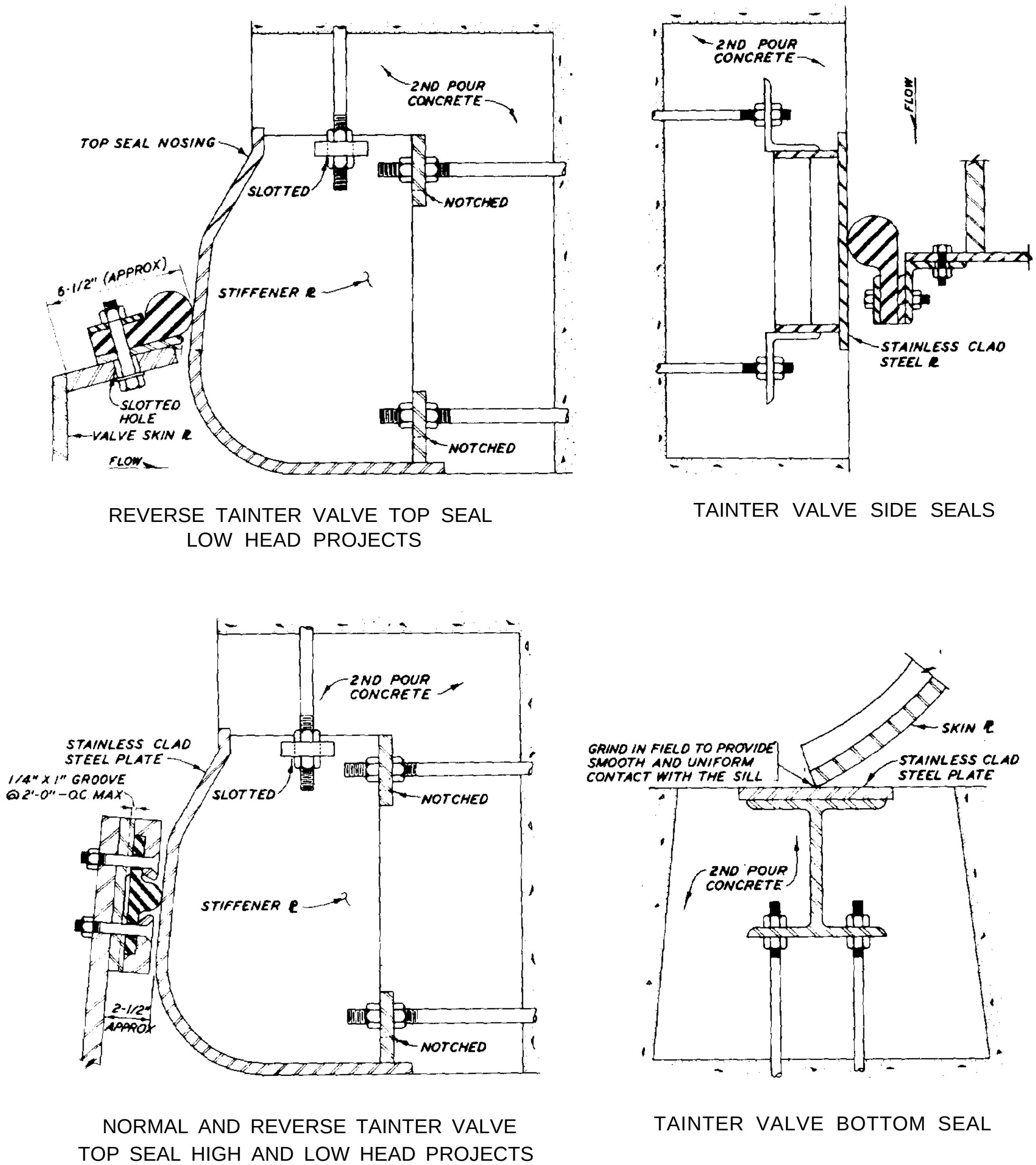
# CHAPTER 4. VALVE SEALS

4-1. General. Valve seals are the responsibility, primarily, of mechanical design but the hydraulic designer should be aware of cavitation, vibration, and hoist load problems that can result from poor seals. Leaks around valves in high-lift locks can result in cavitation and possible damage to the culvert or the valve. The seals given as examples in this manual have proved satisfactory; however, other arrangements of seals have also been used successfully. It has been found that inadequate anchorage is one of the major causes of problems with embedded items. The blockouts and anchorage systems shown on the examples of seals given herein are required for proper installation.

4-2. Bottom Seals. Satisfactory sealing across the bottom of a tainter valve can be accomplished by pressure contact of the lip of the valve on a metal sleeper embedded in the culvert floor (see fig. 4-1). The bottom edge of the skin plate should be ground in the field to provide a smooth and uniform contact with the sill plate. Flexible (rubber) bottom seals can be a source of serious vibrations; and since it has been demonstrated that with reasonable care good metal-to-metal contact can be obtained for the full length of the sill, use of flexible seals is not advocated. However, a compression-type rubber bottom seal has been used successfully on high-lift locks by the Walla Walla District.

4-3. Side Seals. Rubber J-type seals are recommended for the sides of the valve, figure 4-1. These seals should bear against and slide along curved stainless steel plates embedded flush with the culvert walls. Also, these plates should extend into the valve well for the full height of the opened valve in order to provide lateral support for the valve in the open position. In several installations where lateral support was not provided for the fully open valve, the jostling action of the highly turbulent flow circulating in the valve well resulted in loosening of trunnion anchorages and other damage. The side plates should be free of irregularities that might cause the rubber seal to wear or lose contact. It is very important that the rubber seals be adjusted to maintain a relatively uniform contact with the seal plates. Loss of contact, in addition to allowing leakage, can result in seal flutter which will cause serious vibrations throughout the valve.

4-4. Top Seals. The seal at the top of the valve is likely to present more problems than those at the sides and bottom. The top seal must mate smoothly with the top seal plate and, at the same time, allow the bottom edge of the valve to rest with sufficient pressure on the sill to seal the valve at the bottom. A prolonged rubbing contact and slow breakaway are very undesirable as they are conducive to vibration.




NOTES: 1. PROVIDE 0.060" ABRASION RESISTANT FLUOROCARBON FILM ON RUBBER SEALS
2. SEAL RETAINER BOLTS SHOULD BE LOCKED TO PREVENT LOOSENING DUE TO VIBRATION

Figure 4-1. Valve seals

Also, the portion of the top seal including the seal bracket that extends beyond the skin plate is exposed to an unbalanced head equal to the lift. This head decreases as the seal moves away from the top seal plate and becomes zero when the distance between the top seal and any part of the gate well face exceeds the distance between the skin plate and the seal plate. In a reverse tainter valve at the beginning of the opening cycle, the hoist must overcome this unbalanced head at the same time it is "breaking" the seals and this may result in the peak load on the hoist. Obviously, it is desirable to maintain the seal projection on the valve as short as practicable.

a. Two designs for the top seal are shown in figure 4-1. One design is suitable only for reverse tainter valves in locks with relatively low lifts (about 40 ft or less). In this design, the seal bracket projects about 6 in. (horizontally) beyond the skin plate. The unbalanced load in pounds per foot of valve width with the valve closed is equal to 31.25 times the lift in feet. The other design is suitable for all lifts with the valve in either the reverse or normal position. The unbalanced load (downpull for reverse tainter valve, uplift for normal) on this seal in pounds per foot of valve width is only about 13 times the lift in feet. A J-type seal also can be used in high-lift projects, but the clearance between the skin plate and seal nose should not exceed about 2-l/2 in. and the seal bulb should be partially constrained to prevent excessive flutter as the seal is broken.

b. It is difficult to prevent leaks at the junction of the side and top seals. For projects with lifts up to about 40 ft, a molded corner that in effect makes a continuous seal is desirable. However, molded corners tend to transmit movement of the side seals to the top seals and have caused working and eventual failure of the top seals. An arrangement that allows independent movement of side and top seals is suggested at projects with lifts greater than about 40 ft.

# CHAPTER 5. RECESSES FOR UNWATERING BULKHEADS

5-1. General. To allow for service and repair to a valve without taking the lock out of operation, bulkhead recesses are provided on the high- and low-head sides of each of the four valves. Each recess consists of slots in the sides of the culvert, an opening in the culvert roof, and a shaft extending to the top of the lock wall. Although it is unlikely that more than one valve will be under repair at a given time, two sets of bulkheads normally are provided at each project to block upper and lower pools from the culvert system for unwatering of the lock. For storage, the bulkheads usually are held near the top of the shafts by dogging devices.

5-2. Bulkhead Recesses. Open-well bulkhead recesses on the high-head sides of the four valves have caused no problems during filling and emptying of the lock. However, there is one known case of a surge in the bulkhead recess created by operation, as discussed in paragraph 3-3c, lifting the bulkhead off of the dogging devices and then allowing it to slam down with sufficient force to break the dogging devices and drop into the culvert. The lifting force was due primarily to the stored bulkhead restricting flow up the shaft. It is suggested that the shaft be enlarged (see fig. 1-1) at the position of the stored bulkhead.

5-3. Location of Bulkhead Recesses. During the valve opening period, a zone of low and unstable pressures extends about 6-1/2 times the culvert height downstream from the valve. Usually, other considerations make it desirable to locate the bulkhead recess for the low-head side of the valve within this zone. Thus, an open well for the bulkhead recess on the low-head side of the valve would be a potential source for excess air entering the culvert system. Except for recesses on the low-head side of emptying valves discharging outside of the lower approach to the lock (see paragraphs 2-5a and b), the bulkhead recess on the low-head side of each valve should be sealed. Further, it is desirable that this seal be placed just above the level of the lower pool. If placed near the top of the lock wall, oscillations develop in the column of water in the bulkhead shaft and at some valve opening these oscillations interplay with and amplify the oscillations in the recess, causing unstable loads on the valve hoist.